HIGHWAY RESEARCH REPORT

FACTORS INFLUENCING THE DURABILITY OF AGGREGATES

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STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

Interim Report
FHWA No. D-3-15
M&R No. 633476
August 1971

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is an interim research report titled:

FACTORS INFLUENCING

THE

DURABILITY OF AGGREGATES

George B. Sherman
Principal Investigator

Robert D. Hamilton - Robert E. Smith
Analysis & Report

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Hamilton, R. D., Smith, R. E., and Sherman, G. B., "Factors Influencing the Durability of Aggregates," State of California, Department of Public Works, Division of Highways, Materials and Research Department, June 1971. Research Report 633476, Federal Program No. D-3-15.

ABSTRACT: This report completes work performed in Phases 1 and 2 of a currently active 3-phase project. California's durability test was examined for possible improvements through modification or procedural change. Past performance of the test procedure has been evaluated by means of a field sampling program, accelerated degradation tests in the laboratory, and correspondence to determine experience throughout California's eleven highway districts. A discussion on extended use of the durability test is included, and a review has been made of possible alternate durability tests.

The general conclusion was reached that California's durability test has been very effective and no major modifications were recommended. It was further recommended that this test be retained by the California Division of Highways as no satisfactory alternative test procedure has been investigated herein.

KEY WORDS: Aggregates, bases, degradation, durability, sampling, soundness, specifications, subbases, test methods.

ACKNOWLEDGMENTS

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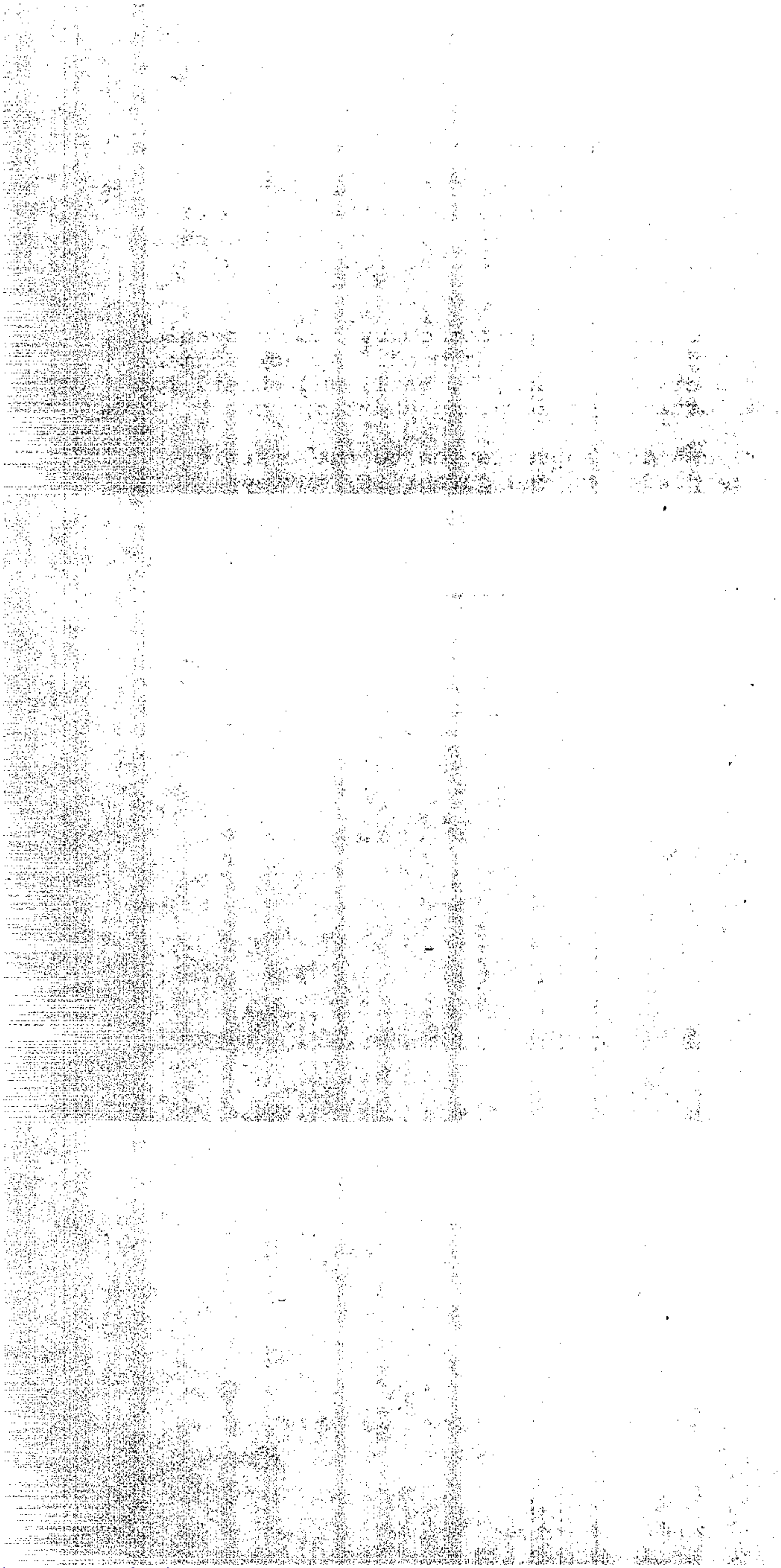
The authors wish to express their appreciation to the District Materials Engineers who responded to the durability survey questionnaire.



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INTRODUCTION

A large proportion of funds expended annually for highway construction go towards the purchasing, processing, and placing of mineral aggregates. In California, it is estimated that approximately twenty-five percent of the total highway costs are for this purpose. Obviously, the quality control of aggregates requires high priority to insure that only acceptable materials are used. One of the most important and desirable characteristics of aggregates is adequate durability. In order to provide a long service life of the pavement structure, the aggregates used therein must have sufficient durability to resist mechanical and chemical forces to which they are subjected.

California's durability test (Test Method No. Calif. 229)[1] was developed to prequalify aggregates proposed for use in state highway construction. Basically, this test measures an aggregates resistance to generating fines when agitated in the presence of water. Separate and different test procedures are used to evaluate the coarse and fine portions of a material. Material passing the 3/4-inch sieve and retained on the No. 4 sieve is tested to determine the durability of the coarse portion (Dc), and a representative sample of material passing the No. 4 sieve is tested for durability of the fine portion (Df). The durability index of the material is defined as the lowest of the two values so obtained, and this is the controlling value for specification purposes.

Durability index requirements for aggregate bases and permeable materials have been included in the California Standard Specifications[2] since 1964. The revised 1969 Standard Specifications included additional reference to the Df test for fine concrete aggregate. Our most recent (Jan 1971) Standard Specifications have increased further the application of the durability test by including a Dc requirement for slope protection rock.

A request was submitted in February, 1965, for Federal funds to finance this research project, and approval was received by May 1965. This research was initiated because it was felt necessary to: examine possible improvements to the durability test procedure; investigate areas of possible increased application of the test method; and, evaluate recent performance of this test. The original work plan consisted of 3 phases which were necessarily modified somewhat as the work progressed. The interim report completes essentially two of the three phases and the following subjects are reported herein:

An examination of the correlation between D_c and D_f.
An investigation of a possible durability test for aggregates larger then 3/4".
An evaluation of the effectiveness of California's durability test.
A discussion of increased application of this test.
A review of other types of durability tests.

This research project is currently active but approximately two-thirds complete with submission of this interim report. The final phase of remaining research is the responsibility of the Concrete Section of the Materials and Research Department, and is concerned with the development of a durability test procedure for coarse concrete aggregates.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. No direct correlation was found to exist between the coarse durability index (D_c) and the fine durability index (D_f) for many aggregates. This is partially due to basic differences between the two procedures, but the research evidence also indicates that the two aggregate size fractions have varying degrees of resistance to degradation. It was concluded that no benefit would be obtained by attempting to improve this correlation between D_c and D_f.

2. A practical durability test for + 3/4 inch aggregates was not developed, due to size limitations of available test equipment. Tests with existing equipment yielded poor repeatability on replicate samples of heterogeneous aggregates. Repeatability could be improved by averaging multiple tests, but it was concluded that this was not a practical method for implementation.

3. Three studies were made to evaluate the effectiveness of California's current durability test. They were; a field sampling program, accelerated laboratory degradation, and a survey of District experience with degrading aggregates. It was concluded that the durability test requirements, in conjunction with other aggregate specifications, are effectively eliminating most problem aggregates from use as base materials.

4. Increased application of the durability test for evaluating fine aggregates for concrete, permeable materials, and rock-slope protection materials, has resulted in reduced testing time, reduced test costs, and improved quality control of these aggregates.

5. No alternate durability test procedure has been investigated that can be recommended for adoption by the California Division of Highways.

Recommendations

1. California's existing durability test procedure should be retained without any major modifications. No immediate changes to the specifications limits as set forth in the 1971 California Standard Specifications can be recommended on the basis of this study.

2. The roadway sites investigated in the field sampling program could provide additional valuable data. It is recommended that these same locations be resampled in the future to provide further understanding of base aggregate performance after extensive service to traffic. With the increasing scarcity of aggregates in some locations, it is probably justified to study the possibility of modifying the durability limits for specific aggregates.

BACKGROUND AND OBJECTIVES

Brief History of Durability Tests

Numerous tests have been developed throughout the world to evalauate the resistance of aggregates to mechanical degradation. The Deval tumbler, developed in France to measure this quality of aggregates, was first adopted by ASTM in 1908. The Los Angeles Rattler was developed about 1925 and is probably the most widely used device today to evaluate the abrasion resistance of aggregates.

During the past 20 years the problem of degradation of highway aggregates in some western states of the U. S. has resulted in the development of additional durability tests by Oregon, Washington, Idaho, Alaska and California. Each of these test procedures subject aggregate samples to abrasive or wearing action, either in air or water, and require measuring changes in gradation and/or the amount of generated fines. Although differing considerably in procedure and acceptance limits, each of these have been reported by the various states as being reasonably successful in predicting degradation characteristics of aggregates.

Aggregate Degradation in California

Prior to 1963 the California Division of Highways experienced some pavement structural failures which were attributed to aggregate degradation. At the time of construction these problem aggregates were rated acceptable by existing qualification tests. Located mostly in the coastal range areas of northern California, those aggregates having poor service records are usually weathered volcanics, shales, or composed of clay-bound sandstones. The "Los Osos Basalt," commonly referred to as "Red Rock," is a specific example of an aggregate having low resistance to degradation. This material usually met our previous test limits on Los Angeles abrasion, sand equivalent, and R-value. However, when agitated in water for a few minutes, this aggregate breaks down into fine particles, which cause a reduction in the load carrying capacity of the material.

Development of California's Durability Test

California's durability test was developed largely as a result of the need to predict the degradation that may occur to aggregates during construction and under traffic, and to eliminate these aggregates from further acceptance.

The development of Test Method No. Calif. 229 and its application to highway construction were presented to the Highway Research Board in January 1964.[3]

Basically, the California durability test measures an aggregate's resistance to generating clay sized fines when agitated in the presence of water. The amount and character of the fines are evaluated in terms of an empirical "Durability Index." A fairly good correlation has been established between this durability index and the reduction in R-value after degradation.

Separate test procedures are performed to evaluate the coarse aggregate fraction and the fine aggregate fraction. The lower durability index obtained by either separate test procedure is the controlling value for specification purposes.

The durability index for the coarse aggregate fraction (3/4" to No. 4 sieve sizes) is determined from a 2500 gram test sample of washed material that has been batched to a prescribed grading. The prepared test sample is placed in a washing vessel containing 1000 ml. of water, and agitated in a modified sieve shaker (Figure 1) for 10 minutes. A fractional portion of the wash water, containing the fines produced during the agitation period, is then poured into a cylinder containing a flocculating agent and thoroughly mixed. A sedimentation time is provided by allowing the cylinder to stand undisturbed for 20 minutes. The height of the suspended sediment in the cylinder is then read and recorded. The durability index of the coarse aggregate is a function of this sediment height.

The durability test procedure for fine aggregate (minus No. 4 sieve size) is identical to the procedure used in determining the sand equivalent (Test Method No. Calif. 217)[1] of a material with two exceptions:

1. The test sample is prepared from the residue of washed passing No. 4 sieve material used in the sieve analysis test, and

2. The sample is agitated for 10 minutes in the mechanical sand equivalent shaker (Figure 2) in lieu of 45 seconds.

Durability indices may range from about 90 for such hard materials as quartz down to 5 or less for claybound sandstones and shales.

The current California durability test procedure (Test Method No. Calif. 229-E) incorporates portions of our routine "sieve analysis," "sand equivalent" and "cleanness" tests.[1] This eliminates the need for additional equipment so that district laboratories may perform the durability test by making only minor modifications to existing standard apparatus.

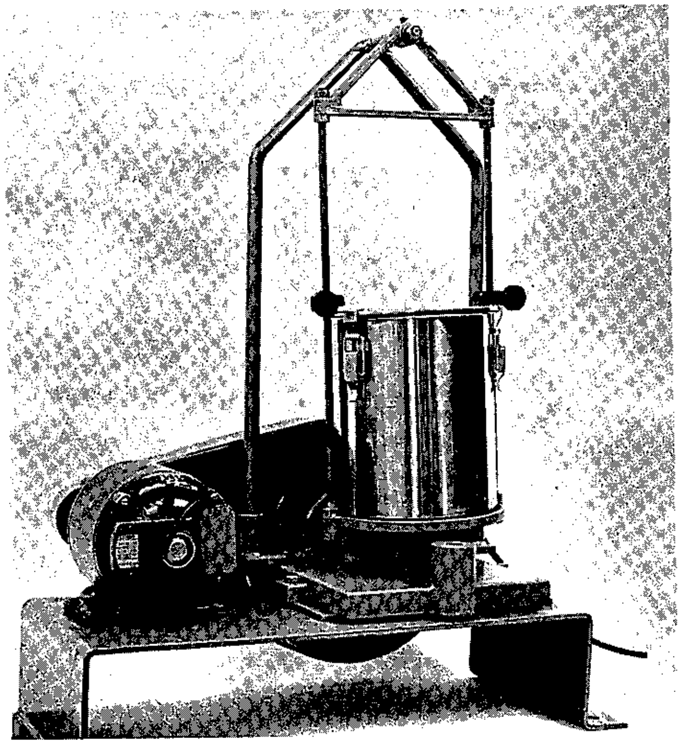


Figure 1

Modified Tyler Sieve Shaker and Washing Vessel for Testing Coarse Aggregate

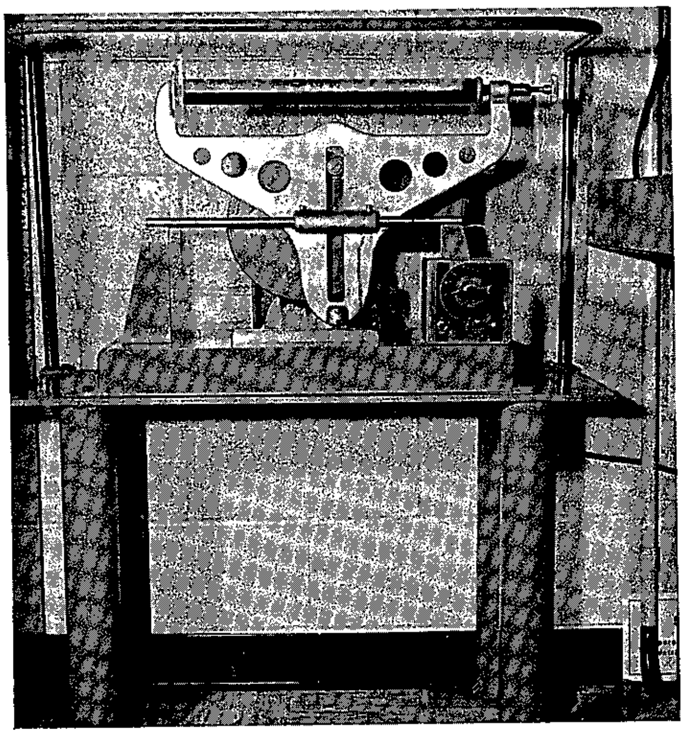


Figure 2

Mechanical Sand Equivalent Shaker and Cylinder for Testing Fine Aggregate

Objectives of this Research Project

The California Division of Highways introduced the new durability test as a specification requirement for aggregate bases in the 1964 Standard Specifications.(2) A minimum durability index was specified in lieu of the existing Los Angeles Abrasion specification.

Selection of the minimum allowable durability indices for aggregate bases was established largely on past experience with problem aggregate sources throughout the State. The minimum durability indices for Class 1 and Class 2 aggregate bases are now specified as 40 and 35 respectively.

Soon after adoption of the durability index test as an acceptance criterion, the work plan for this research project was submitted and approved. It was desired to evaluate the performance of this new test and to examine means of possible improvements through modification to the test procedure. Also, considerable interest had been expressed as to the possibility of expanding the application of this method to control the quality of aggregates used in other areas of highway construction. For example, it was hoped that this durability test could be used as a replacement for the controversial sodium sulphate soundness test for concrete aggregates.

The original work plan listed the objectives of this project under three phases:

Phase 1 was to investigate possible modifications to the test procedure so that (a) test values for coarse and fine aggregate size fractions could be combined into a composite value; and (b) aggregates larger than the 3/4-inch sieve size could be tested.

Phase 2 was to develop test procedures and standards for aggregates used in treated bases, asphaltic concrete, and portland cement concrete.

Phase 3 was to determine the degree of correlation between the durability test and more time-consuming tests such as the sodium sulphate soundness and mortar strength tests.

This interim report completes work performed through Phase 2 of the three phase project. The objectives outlined above for Phase 2 were modified when it was decided that the existing qualification tests for cement treated base aggregates and asphalt concrete aggregates were satisfactory, and further work to implement the durability test for this purpose was not necessary. As the work evolved, the following objectives were pursued and the results are reported herein:

1. An examination of the correlation between coarse durability (Dc) and fine durability (Df).

2. The possibility of development of a satisfactory durability test procedure for testing aggregates larger than 3/4" sieve.

3. An evaluation of the effectiveness of California's durability test in measuring aggregate quality, for which investigations were made in the following areas:

   a. field sampling
   b. laboratory tests
   c. district survey (questionnaire)

4. An investigation of increased application of California's durability test.

5. An examination of durability tests used by other agencies.

DISCUSSION OF WORK PERFORMED

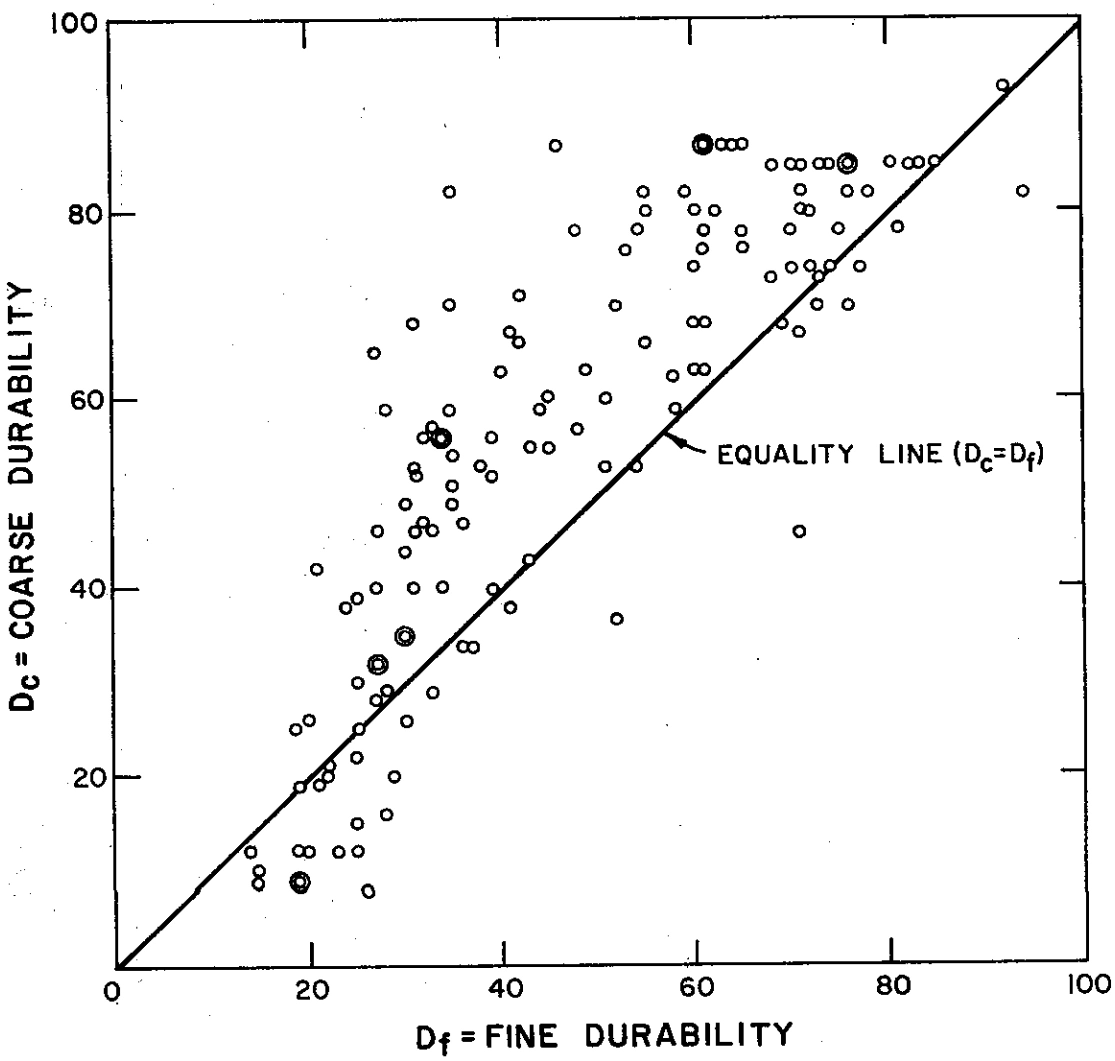
Correlation Between Coarse and Fine Durability Indices

California's durability test was purposely developed to enable utilization of test apparatus which was already available to the district and field laboratories. The coarse durability procedure uses equipment that is required in the performance of California's cleanness test (TM No. Calif. 227).[1] The fine durability procedure requires apparatus specified in the sand equivalent test (TM No. Calif. 217).[1] Consequently, separate and distinctly different test procedures resulted for the durability testing of the coarse and fine portions of an aggregate sample.

The fine durability index (Df) is calculated by the same formula used to determine sand equivalent values. The scale of values may range from 0 to 100 in ascending order of quality. In order to provide a similar range in coarse durability values (Dc), the clay sediment heights obtained in a modified cleanness value test are converted by means of an equation to give Dc values which also range from 0 to 100.

Currently, the California Division of Highway's specifications require minimum durability indices (Df and Dc) of 35 for Class 2 aggregate base and 40 for Class 1 aggregate base. These limits were established by comparing the performance records of a large number of aggregates with their durability as discussed in a report by Hveem and Smith(3).

COMPARISON OF COARSE & FINE DURABILITY INDICES ON ROUTINE SAMPLES FOR 1963-64



Concentric circles indicate two or more plotted points.

Figure 3

Both Dc and Df test results for each individual source must meet these minimum requirements to be acceptable.

Figure 3 shows the relationship between Dc and Df values for more than 100 durability tests performed during 1963 and 1964. Despite fairly wide dispersion, the distribution of data points suggests a curvilinear rather than a linear relationship. If a "best fit" curve were drawn to the data it would cross the shown equality line at about 25. Above this point, Dc values are usually larger than corresponding Df values.

This nondirect relationship between Dc and Df values has resulted in most base aggregates being accepted or rejected on the basis of the Df test result.

Various proposals were made to improve the compatibility of the two test results. Considerable effort was expended in the following directions:

1. Several revised equations were developed to convert coarse durability sediment heights to Dc values.
2. The Dc test procedure was examined with regard to possible modifications such as increased sample size and extended agitation times.
3. The possibility was explored of developing a combined (or composite) durability index directly from the sediment column heights of both tests.

Although some improvement to the correlation between Dc and Df was obtained by these efforts, the benefits did not appear sufficient to justify changing the test method. Further efforts in this direction were discontinued.

Search for a Durability Test for Aggregates Larger Than The 3/4-inch Sieve

The purpose of this work was to develop a routine method of testing the durability of aggregates larger than the 3/4" sieve. It was intended to develop this procedure primarily to evaluate portland cement concrete aggregates of 1-1/2" to 3/4" size, however, consideration would also be given to using it to evaluate other aggregates used in the highway structural section.

The type of test examined was similar to California's Dc procedure for 3/4" x No. 4 size aggregate. A large number of tests were performed with various procedural modifications. Two interrelated problems were experienced in the pursuit of a satisfactory procedure: (1) lack of repeatability of test results on replicate specimens made from heterogeneous aggregates; (2) poor correlation with Dc test results.

Attempts were made to improve test results by:

a. enforcing stricter controls on the test apparatus (e.g.) the shaking action

b. increasing sample size to the maximum permissible by the apparatus

c. varying the agitation time

d. making adjustments to the volume of test water

e. averaging two or more test results on each material

A procedure was finally developed which gave acceptable repeatability on homogeneous aggregates such as sandstone. However, little apparent improvement in repeatability could be obtained on heterogeneous materials, or those aggregates composed of an agglomeration of minerals. Apparently, the developed procedure was extremely sensitive to the presence of poor materials, even in relatively small quantities. Variability in test results on replicate specimens of heterogeneous aggregates could not be eliminated even by taking extreme caution in sampling techniques and sample preparation. It was decided that an average of multiple tests would be necessary to insure a satisfactory level of confidence for purposes of accepting or rejecting materials. It was concluded that the use of multiple tests was not desirable from the standpoint of practical implementation, and work on this phase was discontinued. Further efforts were concentrated on the development of the autoclave as an alternate method of testing the durability of coarse concrete aggregates. Both of these methods are under consideration during the final phase of this research project.

Evaluation of the Effectiveness of California's Durability Test

(a) Field Sampling of Selected Roadway Sites

A sampling program was conducted to examine the amount of degradation of subbase and base aggregates during service. Only roadway sections surfaced with asphaltic concrete were sampled because previous experience in California had shown that aggregate durability problems were generally confined to materials under flexible pavements. It was expected that this investigation would result in a better understanding of aggregate degradation and give an indication of the effectiveness of the durability test as a measure of this property of aggregates.

Eighteen projects constructed in 1960 and 1961 were chosen for investigation. Base aggregate samples were taken on eight of these projects, and subbase samples were obtained on the other

Table 1

Summary of Field Sample Test Results[1] on Aggregate Bases

Project No. and Class of Base[3]	Number of Sampled Stations	Construction - C, Audit - A, Resample - R	Durability Dc (Coarse)	Durability Df (Fine)	R-value	Sand Equiv.	Plasticity Index	Mechanical Analysis % Passing: 1 Micron	5 Microns	#200	#30	#4
1	5	C	42	46	79	28	NP	1	2	6	15	27
Cl 3 AB		A	–[2]	–	79	27	NP	1	3	10	23	41
		R	43	35	82	26	NP	1	3	9	22	43
2	2	C	67	57	80	28	4	1	3	6	11	24
Cl 2 AB		A	–	–	81	36	–	1	4	9	16	35
		R	61	35	82	29	2	2	4	12	23	52
3	2	C	35	28	79	41	NP	1	2	5	22	41
Cl 2 AB		A	–	–	82	27	NP	0	3	9	25	45
		R	32	28	85	29	NP	1	3	9	27	47
4	3	C	54	51	79	31	NP	1	3	13	30	67
Cl 3 AB		A	–	–	80	32	–	–	–	14	31	74
		R	–	49	81	32	NP	2	4	12	29	73
5	3	C	71	65	–	–	–	–	–	–	–	–
Cl 2 AB		A	–	–	79	31	NP	–	–	10	31	49
		R	83	62	82	29	NP	1	3	9	28	47
6	3	C	59	65	79	31	NP	2	3	7	27	53
Cl 2 AB		A	–	–	79	32	NP	3	4	7	26	48
		R	74	62	82	29	NP	1	3	7	26	53
7	3	C	59	47	–	–	–	–	–	–	–	–
Cl 2 AB		A	–	–	81	41	NP	2	3	6	22	51
		R	69	47	82	38	NP	1	3	6	20	51
8	4	C	66	68	80	31	NP	1	3	10	21	46
Cl 2 AB		A	–	–	79	34	NP	2	4	9	21	46
		R	78	66	83	31	NP	1	3	10	22	48

[1]All tests were performed according to California Division of Highways Test Methods.

[2](-) indicates unavailable data.

[3]California Division of Highways, Standard Specifications, 1960.

ten projects. All sampling was carefully performed to obtain representative material, with minimum disturbance due to the sampling procedure itself.

Table 1 is a summary of data collected from those projects sampled for base aggregates. Testing data for each contract are average values for the number of sampling stations shown in the second column. For each project every sampling station was sampled three times as follows:

1. Samples during construction (C) were obtained from the windrowed material prior to spreading and compaction.

2. Audit samples (A) were taken during the record sampling program, from the compacted material, immediately following construction.

3. Resampling (R) was performed at each site after approximately six years of traffic.

Durability tests (Dc and Df) were performed at the time of construction, and also on the resampled base materials after six years service in the roadway. Other laboratory tests performed upon completion of each sampling phase were: R-values, sand equivalents, Atterberg limits, and sieve analyses which included hydrometer analyses for the 5 micron and 1 micron size particles.

Table 1 reveals that none of the sampled projects had sufficient base aggregate degradation to reduce stability as measured by the R-value test. Overall, it was concluded from the tabulated data that no significant changes in plasticity index or sand equivalent values resulted during the six year period. The hydrometer analyses did not reveal any significant increase in clay sized particles for any of the projects.

The sieve analyses results for projects 1 and 2 show significant increases in percentages passing the Nos. 4 and 30 sieves, but much of this degradation occurred during construction. However, the hydrometer analyses and plasticity indices tests do not reveal that any significant amount of clay sized fines were developed. Consequently, it is not surprising that no reduction in R-value was obtained on these materials during the six years of this study.

However, further examination of the data from projects 1 and 2 reveals lower fine durability indices after six years service. This indicates that these aggregates have become more susceptible to degradation, and it is possible that further mechanical breakdown could result in a less stable aggregate. The coarse gradations of aggregates used in projects 1 and 2 at the time of construction may explain the greater amount of particle breakage which occurred on these projects. This indicates the need for specifying well graded materials to provide resistance to fracture caused by compaction and traffic. It appears from this data that particle breakage will be minimized by specifying a well-graded material consisting of a minimum of about 40% passing the No. 4 sieve.

Although the projects sampled for this study were constructed before the durability test was inserted in the Standard Specifications, all aggregates meet our present durability index requirement for Class 2 base material. As no distress has been observed on any of these sampled projects, this program provided some assurance that our durability test limits, in conjunction with requirements on grading, sand equivalent, and R-value, are resulting in the selection of satisfactory materials.

In addition to the projects sampled for base materials, ten projects were sampled for subbase aggregates. None of these sites showed any significant degradation or distress over the six years spanned by the testing program. This data is, therefore, not included or discussed.

(b) Correlation Between Durability Index and R-value Loss for Base Materials Degraded by a Laboratory Method

The durability index obtained by the California Durability Test is defined as a value indicating the relative resistance of an aggregate to producing detrimental clay-sized fines, when the aggregate is subjected to mechanical degradation. The production of these fines is considered detrimental to a subbase or base material because excessive amounts may reduce interparticle friction and reduce the load carrying capacity. The ability of a material to resist lateral deformation when acted upon by a vertical load is termed resistance (R-value) and is measured by TM No. California 301. (1)

The purpose of this study was to determine the correlation between durability index and R-value loss for numerous aggregates when degraded by a laboratory method. The California kneading compactor was used to subject specimens to excessive manipulation in an attempt to produce fines characteristic of those which may result from degradation in the roadbed.

The following is a brief description of the procedure followed in this work. Sources of subbase and base aggregates were sampled to obtain material representing a wide range in durability indices. Briquette specimens 6" in diameter and 3.5" high were fabricated at moisture contents required to give 300 psi exudation pressure in the R-value test. (This moisture content was selected for each sample as it is considered the worst condition reached by a material in place at any time after construction.) Each specimen was moist cured for 16 hours before subjecting to 1000 tamps by the kneading compactor at 300 psi tamper-foot pressure. During the loading, each specimen was maintained in a saturated condition by permitting water from an external reservoir to penetrate upward through the specimen via a porous stone.

In addition to durability and R-value tests, mechanical analysis, Atterberg limits, and sand equivalent tests were performed on each material before and after the 1000 tamps. These additional tests were made to determine the extent of particle breakage, and the amount and type of fine material created by the degradation.

Table 2 shows the data collected on 24 samples, each of which consisted of all minus #4 sieve size material.

The tabulated results generally show that those materials that did degrade sufficiently to cause significant loss in R-value also had:

1. low initial Df values
2. extensive particle breakage after compaction
3. increased plasticity indices after compaction
4. increased amount of clay-sized particles after compaction
5. reduced sand equivalent values after compaction

Figure 4 shows the relationship between R-value reduction and Df values for all 24 tests.

A definite trend is shown towards greater loss in stability (R-value) with decreasing fine durability index (Df). It is important to note that 7 of the 15 aggregates having Df values less than 45, had losses in excess of 30% of their original R-values.

It was concluded that the kneading compactor method used to degrade aggregate samples in the laboratory caused sufficient alteration of aggregate characteristics to result in R-value decreases for many of the materials. A comparison of Tables 1 and 2 indicate that the chosen laboratory method applied higher mechanical effort than that normally applied to base materials by construction methods and traffic over a six year period. In contrast to the kneading compactor test results, none of the sampled roadway materials were degraded sufficiently to show any R-value (stability) loss during six years of service.

Although no correlation between the field and laboratory test results was found, the kneading compactor study provided further assurance that our durability test is a measure of the expected performance of base aggregates that may be subjected to mechanical

Table 2

Results of Kneading Compactor Degradation Tests
(Minus No. 4 Sieve Material)

Sample Number	B = before compaction A = after compaction	Fine Durability (Df)	R-value	Sand Equivalent	Plastic Index	Mechanical Analysis % Passing 1 Micron	5 Microns	#200	#30	#4
64-1436	B	28	75	28	NP	3	5	16	46	100
	A	34	29	18	7	9	17	37	66	100
65-4240	B	27	79	51	NP	0	2	6	31	100
	A	30	36	39	5	3	9	23	47	100
62-5936	B	33	78	30	NP	4	7	18	49	100
	A	37	38	20	3	7	12	32	60	100
64-1269	B	44	75	37	NP	4	6	15	37	100
	A	62	48	24	1	7	13	26	50	100
67-3349	B	28	50	26	8	5	10	24	58	100
	A	49	26	18	9	9	15	35	67	100
67-3421	B	22	75	30	NP	1	4	22	57	100
	A	35	50	11	4	11	19	39	84	100
61-1750	B	57	73	60	NP	1	2	6	33	100
	A	69	57	28	1	5	10	20	45	100
67-3347	B	55	74	26	NP	3	8	23	68	100
	A	65	59	22	3	5	12	28	69	100
64-1267	B	24	32	17	6	8	15	35	65	100
	A	26	21	14	7	11	22	42	75	100
67-3351	B	32	76	39	NP	1	5	13	46	100
	A	39	67	21	4	5	12	29	58	100
61-1401	B	76	82	28	NP	4	9	21	42	100
	A	-	76	21	1	6	14	31	49	100
61-4116	B	73	74	29	NP	3	4	21	56	97
	A	-	71	26	NP	5	8	21	60	97
67-3426	B	22	80	34	NP	0	4	23	57	100
	A	33	78	17	2	-	-	36	71	100

Table 2 (Con't)

Results of Kneading Compactor Degradation Tests
(Minus No. 4 Sieve Material)

Sample Number	B = before compaction A = after compaction	Fine Durability (Df)	R-value	Sand Equivalent	Plastic Index	Mechanical Analysis % Passing 1 Micron	5 Microns	#200	#30	#4
62-5944	B	37	78	69	NP	1	3	9	28	100
	A	-	76	30	2	4	6	18	39	100
67-3348	B	43	61	21	4	5	11	36	68	100
	A	49	59	16	6	8	16	39	69	100
67-3326	B	68	81	45	NP	1	4	18	44	100
	A	75	79	26	NP	3	10	29	53	100
67-3422	B	88	78	72	NP	0	2	4	35	100
	A	91	76	43	NP	-	-	12	43	100
67-3381	B	75	77	93	NP	0	1	3	45	100
	A	89	76	57	NP	-	-	11	50	100
64-1664	B	35	78	62	NP	1	3	8	37	100
	A	46	78	39	NP	2	4	14	48	100
65-3843	B	34	82	37	NP	-	-	19	52	100
	A	32	80	33	NP	-	-	22	60	100
66-2689	B	71	78	75	NP	1	3	7	53	100
	A	76	78	41	NP	0	3	14	57	100
67-3350	B	73	79	73	NP	0	2	8	44	100
	A	79	79	53	NP	2	4	17	54	100
67-3327	B	77	84	61	NP	2	5	23	40	100
	A	77	84	53	NP	2	6	29	47	100
61-2979	B	70	72	35	NP	3	6	12	50	100
	A	-	73	27	NP	4	8	16	56	100

FINE DURABILITY INDEX VS R-VALUE REDUCTION FOR BASE MATERIALS DEGRADED BY THE KNEADING COMPACTOR

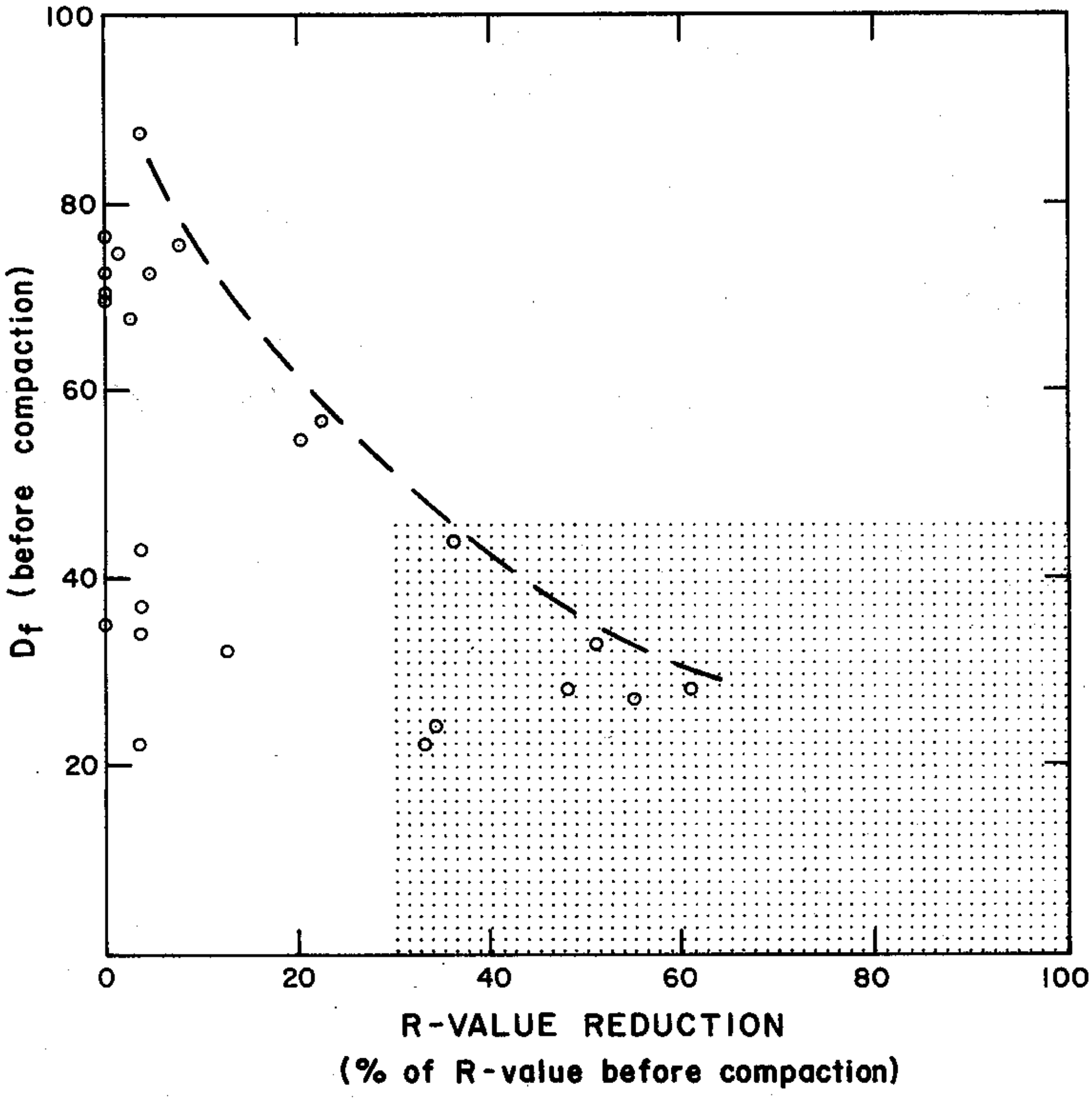


Figure 4

degradation in a saturated environment. It would appear that unacceptable aggregates are being effectively eliminated by the durability test specifications.

c. Statewide Durability Study

A questionnaire was submitted to each of the eleven District Materials Engineers within the California Division of Highways. The purpose of this survey was to determine the extent of aggregate degradation throughout the State, and to determine the effectiveness of our present durability test specifications. It was expected that this approach would assist in identifying problem aggregates which could be sampled for testing under Phase 3 of this research program.

The first question asked for a list of failures in highway structural sections that could be attributed to degradation. Replies from the district representatives show that few failures in recent years can be attributed solely to aggregate degradation. Only two districts reported degradation as the primary cause of failures. Of these two districts, one mentioned a structural failure of crushed base aggregate on a project constructed in 1949, long before our present durability test procedure was devised. The other district listed three specific cases of degradation which were primarily due to degraded aggregate in the asphaltic concrete. However, it is noted that the durability test is not required for asphaltic concrete aggregates by the California Division of Highways. The District Materials Engineer remarked that "adequate durability and soundness test specifications would have precluded these failures." A third district described one project where it was strongly suspected that degradation caused failure; however, this was an unusual overlay design. A cushion of aggregate base and surfacing was placed over an existing pavement, and subsequent failures indicated degradation of the "sandwiched" aggregate. This project was completed before our durability test requirements were included in the Standard Specifications.

The second question asked for the location of any known substandard aggregate sources that were not included under replies to the first question. Replies did not reveal many known problem aggregates in most of the districts. In general, most degradable aggregates appear to be confined to the northern and coastal areas of the State. In these locations it is frequently necessary to treat or stabilize aggregates for use as base course because of the low durability indices, or confine the use of such aggregates to frontage roads and shoulders. One aggregate (mentioned previously) known to have poor durability characteristics, is the "Los Osos Basalt" or "Red Rock." This aggregate is now effectively eliminated by our present durability test.

The third and final question in this survey concerned the possible successful usage by cities or counties of aggregates which have been rated unacceptable by State criteria. Answers to this question indicate that some counties and cities are using some of these poorer aggregates with some success. However, the information received was not detailed as to the sources of these materials and their actual performance records. One district representative, who reported that a few cities and counties are successfully using some State-rejected aggregates, suggested caution in drawing any conclusions from these claimed successes, because in many cases aggregates used in these roads and streets are not subjected to comparable loads and other conditions experienced on State highways.

In general, the result of this durability survey has provided assurance that the present durability test requirements are successfully eliminating most known degradable aggregates.

Increased Application of California's Durability Test

Since the development of Test Method No. Calif. 229, its application has been included in various materials specifications for the California Division of Highways. Originally developed for base aggregates, this test procedure is also now referred to in the specifications for permeable materials, rock slope protection material, and fine concrete aggregates.

A durability test requirement, for permeable material, has been given in the Standard Specifications since 1964. This has enabled a better evaluation of these materials, and has replaced the previously specified Los Angeles Rattler test.

The durability test is now specified for rock slope protection (rip-rap). A paper titled "Evaluation of Rock Slope Protection Material"(4) was presented at 49th Annual Meeting of the Highway Research Board in January 1970. This paper describes the reasons for the adoption of this test which is used in conjunction with the absorption test (Test Method No. Calif. 207-D).(1) The formula combining the results of these two tests gives excellent correlation with known serviceability. A more rapid evaluation of rip-rap materials is now possible since the sodium-sulfate soundness test requirement has been abolished.

Concurrent with this research project, a study was completed which resulted in the incorporation of the durability test for determining acceptance of fine aggregates for portland cement concrete, in lieu of the sodium sulphate soundness test. This research showed that, based on results of 425 tests, soundness losses exceeding the maximum specified 10% are not obtained on these aggregates which have a durability index above 60. Incorporation of this durability test specification has further reduced the number of time-consuming and expensive soundness tests.

An Examination of Durability Tests Used by Other Agencies

A review of literature on aggregate degradation reveals that various agencies have developed or use different test methods to measure aggregate durability. The purpose of this portion of the study was to determine whether it would be advisable for the California Division of Highways to replace it's current durability test with one of these other procedures.

The following criteria were established as necessary prerequisites of a possible alternate test method. A satisfactory test should:

1. Measure the quantity of degraded fines (minus #200 sieve material).
2. Provide fairly rapid test results
3. Require no special and/or expensive equipment
4. Be practical as a field laboratory method

Several possible alternatives to TM No. Calif. 229 were eliminated from further consideration because they did not satisfy the above requirements. As a result, only one procedure was chosen for further evaluation and a limited number of comparative tests. This selected durability test is sometimes referred to as the "Modified Minor Method," developed and currently used by the State of Washington.(5) Alaska uses a slightly modified version of the same method.

Although the Washington and California durability tests are basically similar in that each measures the quantity of fine material (minus #200 sieve) produced by self-abrasion of aggregate particles in water, the procedures differ considerably in such features as sample size, aggregate particle size, sample preparation, method and rate of agitation, conversion formula, and acceptance limits. Table 3 has been included to show pertinent features of both tests for comparison.

Table 4 shows the results of comparative tests performed on four different aggregate sources. For each material source, three individual tests were run by each procedure on replicate samples.

Table 3

Comparison of Washington and California Durability Test Procedures

	Washington D value	California Dc	California Df
Sample preparation size and weight	Material crushed to pass 1/2" sieve and washed on #10 sieve. 1/2" x 1/4" - 500 grams 1/4" x #10 - 500 grams Total weight 1000 grams	Aggregate from pit source or stockpile washed on No. 4 sieve separated and combined (normally) to following. 3/4" x 1/2" - 1050 grams 1/2" x 3/8" - 550 grams 3/8" x #4 - 900 grams Total weight 2500 grams	A 3oz. measuring tin is filled level from a prewashed 500 gram test sample of passing #4 sieve material. This 3 oz. cup holds approximately 120-150 grams of material.
Agitation Procedure	20 minutes in 200 cc of water in a 7-1/2" x 6" plastic cannister in a sieve shaker set at 300 oscillations per minute with 1-3/4" throw.	10 minutes in 1000 ml water in a 2 gallon steel pot, agitated at 285 cpm in modified Tyler sieve shaker with 1-3/4" throw.	10 minutes in sand equivalent tube and shaker with 4" of diluted $CaCl_2$ solution.
Determination	Wash water, passing #200 sieve, placed in a graduate and filled to 500 ml mark. Transfer aliquot portion to SE cylinder, with 7 ml of SE stock solution, fill to 15", invert 20 times & take sediment column height at 20 minutes.	Aliquot portion of wash water passing #200 sieve put in SE cylinder with 7 cc of SE stock solution. Fill to 15" mark, invert 20 times and take sediment height at 20 minutes.	Read and compute the same as the sand equivalent test, clay and sand readings taken after 20 minutes standing time.
Calculation of Test Result	$D = \frac{15-H}{15+1.75H} \times 100$ H = sediment height D = 0 is poor material D = 100 is excellent material D = 50 is doubtful material	Dc = 30.3 + 20.8 CTN (0.29 + 0.15H) where CTN = cotangent of value shown expressed in radians. Lowest of Dc or Df values is used as durability index. For aggregate base, present specs are 40 min for Class 1, 35 min for Class 2.	$Df = \frac{\text{sand reading}}{\text{clay reading}} \times 100$

Table 4

Comparative Durability Testing Data

Aggregate Source	Test No.	Calif. Test Method Dc	Calif. Test Method Df	Wash. Test Method D factor
I	1	58	37	19
	2	65	42	29
	3	62	40	17
	Average	62	40	22
II	1	68	52	26
	2	70	63	26
	3	70	66	28
	Average	69	60	27
III	1	67	56	25
	2	67	55	26
	3	65	60	27
	Average	66	57	26
IV	1	85	32	56
	2	85	31	57
	3	85	32	55
	Average	85	32	56

A plot of these limited number of test results indicates that a trend exists towards a reasonably good curvilinear relationship between California "Dc" index and Washington "D" factor. This supports previous findings by Breese (6) in a report which compares a number of different degradation tests. Breese found that the relationship existing between the values of the modified Minor D and the California Dc, for 38 sets of data, gave a correlation coefficient of 0.876. This good correlation is not surprising since California's Dc procedure closely resembles the Washington test procedure (as shown in Table 3).

The tabulated data further illustrates that Df values are frequently lower than the corresponding Dc values for the same material. Using aggregate source IV as an example, the coarse fraction is shown to be durable by both the California Dc and Washington D tests. However, the fine fraction was found to be subject to degradation as shown by California's Df test result, and would be rejected for base material by current California specifications. Since the amount of material finer than the No. 30 sieve may represent as much as 30% of the total aggregate weight, it is considered important to evaluate the durability of this portion for use as base material.

This testing program indicated that repeatability of the Washington test procedure is about equal to repeatability by California's procedure. The Washington test is considerably less detailed and simpler to follow, and yields one durability value from a single test. Therefore, it is less time consuming and probably less expensive to perform than California's test.

However, California's combined durability test measures the resistance to degradation of all material sizes smaller than the 3/4-inch sieve. This is considered to be very representative of the material as used because normally about 95% of base materials are less than the 3/4-inch sieve. It was concluded that retention of the Df test is necessary in order to evaluate the durability of the fine portion of this material since:

(a) Research by California has indicated that the minus No. 4 sieve material is frequently more degradation prone in-service than the coarser sized material.

(b) Contractors in California occasionally elect to combine materials from different sources to meet specification requirements for base materials.

It is therefore recommended that the California Division of Highways retain the present combined durability test procedure (TM No. Calif. 229-E). No alternate method has been examined that can be recommended for use at this time. Also, in spite of the fact that the rating scale for aggregates given in the Washington test method (Table 3) would appear to reject many materials rated as acceptable by California specifications, no adjustment to California;s acceptance limits are recommended, based on the findings of this research project.

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